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Diversity and structural complexity of mangrove forest along Puerto Princesa Bay, Palawan Island, Philippines

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Abstract The paper describes the diversity and structural complexity of mangrove forest along Puerto Princesa Bay, Palawan Island, Philippines. Occurrence of 28 mangrove species and 11 floral associates were found, which identifies the entire bay as one of the most diverse mangrove forests in the country. Of the six coastal barangays surveyed, San Pedro had the highest diversity index, $H' = 0.912$ while Sta Monica had the lowest, $H' = 0.349$. Mangrove stands are structurally simple with two types of vegetation, fringe and riverine that further constitute five distinct mangrove zones named according to dominating species, *Rhizophora-Sonneratia*; *Rhizophora-Sonneratia-Lumnitzera*; *Rhizophora-Lumnitzera-Xylocarpus*; *Rhizophora-Xylocarpus*; and *Rhizophora-Avicennia*. Commonality among these zones is obvious as revealed in Bray-Curtis cluster analysis. Structural features differed across zones. Trees of larger dbh, 104.5 cm and higher species richness, a total of 15 species, were found in zone 1 while those that comprised the highest basal area, 438 m^{-2} ha^{-1} and density, 8100 ha^{-1} from zones 2 and 4, respectively. Zones 1 and 4 are fringing mangrove forests. Degrees of perturbations greatly depend on human access to mangrove areas. Garbage dumping, occasional cutting of trees, soil erosion, and encroachment of human settlers were identified as potential threats to mangrove forest along the bay.

Introduction

Mangrove forest is one of the vital ecosystems in tropical countries. The Philippines alone is a home to at least 39 mangrove species (Sinfuego and Bout, 2014; Primavera et al., 2004) and similar to other regions, the various natural products and ecological services (Rönnbäck, 1999; Clough, 2013) of this resource are well recognized in the country, including its role in climate change mitigation (Donato et al., 2011; Sheeran, 2006).

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Palawan has an extensive mangrove forest at 51,346 ha in 1998, representing 3.63% of the total land area of the province (PCSDS, 2004). Presidential proclamation 2152 of 1981 declared the entire island province as ''Mangrove Swamp Forest Reserve'' (http//www.puertoprincesa.ph, 2012). To date, nearly 31, 507 ha of mangrove forest in the island-province are highly protected under the International Union for Conservation of Nature (IUCN), and three species, *Ceriops decandra*, *Aegiceras floridum* and *Lumnitzera littorea* with threatened conservation status (Long and Giri, 2011) are widely distributed in some of its localities.

Mangrove ecosystems in nearly all municipalities of Palawan are well documented. Accordingly, Palawan has 23 ''true mangrove'' species. Species richness ranged from 8 to 17 per municipality of which Dumaran and Roxas in northern part of the island have the maximum number of species. *Rhizophora apiculata*, *Sonneratia alba*, and *Bruqueira gymnorrhiza* dominate the mangrove flora of the island (PCSDS, 2004, 1999).

Mangroves of Puerto Princesa constitute 11.7% (5995 ha) of Palawan's mangrove cover. Major mangrove forests in the city have low volume stands due to deforestation rate of 10 has per year, which may be related to increasing number of fishponds, 530 units in 1998 from only 103 units in 1992 (PCSDS, 2004). In Puerto Princesa Bay alone, 150 ha mangrove area is covered by Fishpond Lease Agreement (FLA) (http//www.puertoprincesa.ph, 2012).

Available information on mangrove composition and structure along Puerto Princesa Bay are scarce. The latest available reference reported 18 true mangrove species from nine coastal barangays along the bay (PCSDS, 2006). Earlier attempts made to assess the status of mangroves in the area gave insufficient record on species composition, only 5–14 species, due to limited number of areas surveyed (Becira, 2005; Aliño et al., 2001). Nonetheless, mangrove species composition, community structure, growth, and recruitment in some portions of the bay were initially investigated.

This study was conducted as part of the Commission on Higher Education's Research and Development Program for Marine Biodiversity along Bohol and Sulu Seas. After more than a decade, additional accounts on mangrove's diversity and structural complexity from Puerto Princesa Bay are wanting.

Materials and methods

The study site

Puerto Princesa Bay, 9°40′N to 9°47′N and 118°40′E to 118°47′E, is a relatively shallow bay located in the mid-eastern coast of mainland Palawan, south of Puerto Princesa City. It covers 20 coastal barangays with a land area of 25,688 ha (www.puertoprincesacity.gov.ph, 2012). Mangrove survey was conducted in six coastal barangays along the bay namely; San Pedro, Tiniguiban, Sicsican, Irawan, Iwahig and Sta. Lucia (Fig. 1).

Sampling techniques

Mangrove vegetation assessment followed the standard protocol described by English et al. (1997) with slight modification. In each sampling station, at least two transects, 50–100 m, depending on the extent of mangrove cover, were laid perpendicular to the shore and/or riverbank. A 10 m × 10 m plot was

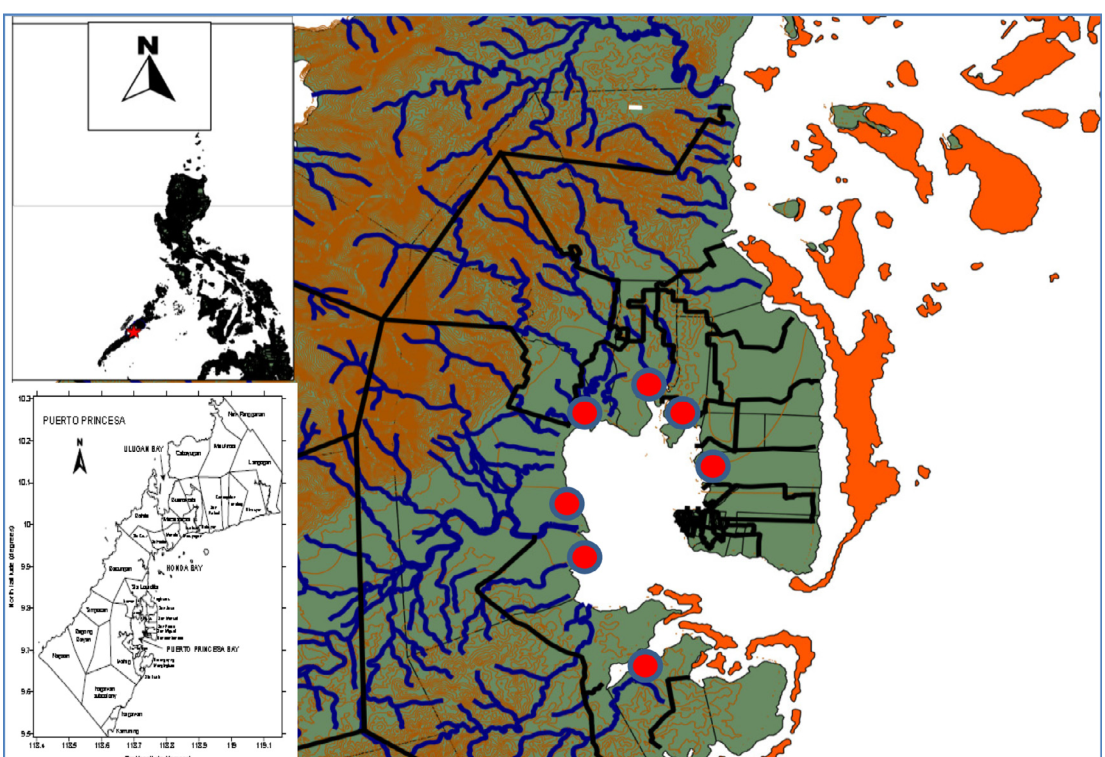


Figure 1 Map of the Philippines (inset) showing the location of Puerto Princesa Bay and the seven sampling stations (red-filled circles).

established along the transect line at certain interval, 10–50 m, depending on the prevailing species zonation pattern.

Plant identification and data analyses

Individual plants found within the plot were identified following the nomenclature of Primavera and Sadaba (2012), Primavera et al. (2004), Feller and Sitnik (1996), and Tomlinson (1986). For each identified species, basic vegetation parameters such as the diameter at breast height (dbh), basal area, and density were measured. Data analyses utilized the Biodiversity Professional Software (McAleece et al., 1997) for species diversity indices (Shannon-Weiner) and multivariate (Bray-Curtis) tests. Direct observation on the surrounding environment of each plot was likewise done to record the existing potential threats to mangrove resource in the area.

Human-resource interaction

Human-related disturbances to mangrove forest were assessed using through actual observation by the researchers. Disturbances observed were verified using the Focused Group Discussion (FGD) and the Key Informant Interview (KII). Information generated were analyzed through descriptive statistics e.g. the frequency count and percentages.

Results

Species diversity

A total of 28 mangrove species and 11 floral associates were recorded from Puerto Princesa Bay. This represents 27 true

Table 1 Mangrove species composition along Puerto Princesa Bay, Palawan Island, Philippines.

Family	Scientific name	Local name
True Mangroves		
Acanthaceae	*Acanthus ebracteatus* Vahl.	Lagiwliw, ragoyroy
Avicenniaceae	*Avicennia marina* (Forsk.) Vierh	bungalon, api-api
	Avicennia officinalis L.	bungalon, api-api
	Avicennia rumphiana Hall. f.	bungalon, api-api
Bombacaceae	*Camptostemon philippinensis* (Vidal) Becc	gapas-gapas
Combretaceae	*Lumnitzera littorea* (Jack) Voigt.	libato, tabao
	Lumnitzera racemosa Willd	libato, tabao
Euphorbiaceae	*Excoecaria agallocha* L.	buta-buta
Meliaceae	*Xylocarpus granatum* Koen	tabigi
	Xylocarpus moluccensis (Lam.) M. Roem	piagao
Myrsinaceae	*Aegiceras corniculatum* (L.) Blanco	tinduk-tindukan
	Aegiceras floridum Roem. and Schult	tinduk-tindukan
Myrtaceae	*Osbornia octodonta* F. Muell.	tawalis
Arecaceae	*Nypa fruitican* (Thunb.) Wurmb.	nipa, sasa
Pteridaceae	*Acrostichum aureum*	palaypay, lagolo
	Acrostichum speciosum	palaypay, lagolo
Rhizophoraceae	*Bruguiera cylindrical* (L.) Blume	pototan, busain
	Bruguiera gymnorrhiza (L.) Lam.	pototan, busain
	Bruguiera sexangula (Lour.) Poir.	pototan, busain
	Ceriops decandra (Gridd.) Ding Hou	malatangal
	Ceriops tagal (Perr.) C.B. Rob.	tangal
	Rhizophora apiculata Blume	bakaw lalaki
	Rhizophora mucronata Lam.	bakaw babae
	Rhizophora stylosa Griff.	bakaw bato
	Scyphiphora hydrophyllacea Gaertn.	nilad
Rubiaceae	*Sonneratia alba* J. Smith	pagatpat
Sonneratiaceae	*Sonneratia caseolaris* (L.) Engl.	pedada
Sterculiaceae	*Heritiera littoralis* Dryand. Ex W. Ait.	dungon, dungon-late
Floral associates		
Apocynaceae	*Cerbera manghas* Linn.	baribai, buta-buta
Asclepedeaceae	*Hoya* sp.	wax vine
Combretaceae	*Terminalia catappa* Linn.	talisay, kalisai
Euphorbiaceae	*Glochidion littorale* Blume	bagnang lalaw, sagasa
Fabaceae	*Breynia vitis-idaea* (Burm.f.) C.E.C..Fischer	matang-ulang, sungut-olang
	Abrus precatorius Linn.	saga-saga, oyang-ya
	Albizia retusa Benth.	kasay, balunos
	Caesalpinia crista Linn.	bayag-kambing, dalugdug
	Caesalpinia sappan Linn.	sibukao, sappan
	Derris trifoliate Lour.	asim-asiman, sabuko
	Millettia pinnata (Linn.) Panigrahi	bani, balikbalik
Flagellariaceae	*Flagellaria indica* Linn.	baling-uai,huak, uag
Malvaceae	*Talipariti tiliaceum* (Linn.) Fryxell	balibago, malabago
Rubiaceae	*Morinda citrifolia* Linn.	nino, lino, apatot

mangrove species from 14 families and 15 genera (Table 1). Species richness differed across sampling sites of which barangay San Pedro had the highest diversity index (H′ = 0.912) followed by barangays Iwahig Station 4 and Purok Sandiwa, San Pedro with 0.768 and 0.760 H′ indices, respectively. Sta Monica had the lowest diversity index, H′ = 0.349 despite having a total of eight mangrove species (Table 2). Three IUCN threatened and near-threatened species, *C. decandra*, *A. floridum* and *L. littorea* were found in the study area.

Table 2 Shannon diversity indices at mangrove sampling stations along Puerto Princesa Bay, Palawan Island, Philippines.

Zone	Sampling station (Barangay)	Shannon diversity index (H′)
1	Tiniguiban	0.739
	Sandiwa, San Pedro	0.760
	Sta. Lucia (Station 1)	0.676
2	Sta. Lucia (Station 4)	0.627
	Iwahig (Station 4)	0.768
	Iwahig (Station 3)	0.604
	Iwahig (Station 2)	0.749
3	Sta. Monica	0.349
	Sicsican	0.581
	Iwahig (Station 1)	0.567
	Sta. Lucia (Station 2)	0.470
4	Sta. Lucia (Station 3)	0.515
5	Irawan	0.598
	San Pedro	0.912

Vegetation types

Cluster analysis classified the 14 sampling sites into five distinct zones based on species composition and basal area (Fig. 2). Zone 1 includes three sampling sites, the Tiniguiban (TNG), Purok Sandiwa (SDW), and Sta. Lucia- Station 1 (STL1). The largest dbh recorded from this zone belonged to *L. littorea* (65.7 cm) but the highest basal areas were observed from *S. alba* at 41.53, 39.88, and 103 m^2/ha in TNG, SDW, and STL1, respectively. Zone 2 includes the Sta. Lucia- Stn 4 (STL4), Iwahig- Stn 4 (IWH4), Iwahig- Stn 3 (IWH3), and Iwahig- Stn 2 (IWH2). *Xylocarpus granatum* had the largest dbh (69.62 cm) and highest basal area in IWH2 and IWH3 with 142 and 103.75 m^2/ha, respectively while the *L. littorea* in STL4 with 100.22 m^2/ha. Zone 3 comprises the mangroves of Sta. Monica (STM), Sicsican (SSC), Iwahig Stn 1 (IWH1) and Sta. Lucia Stns 2 and 3, (STL2 and STL3) with *S. alba* having the largest dbh and highest basal areas, 74.16 cm and 31.77 m^2/ha, accordingly. Mangroves of Irawan (IRW) constitutes zone 4 with *Xylocarpus mollucensis* having the largest dbh (21.3 cm) and highest basal area (46.36 m^2/ha). Transect 1 in this zone is a reforested area dominated by *Rhizophora mucronata* and *Rhizophora stylosa* with dbh ranging from 5.0 to 7.0 cm. Such dbh were comparably smaller than *Rhizophora* from natural stands with 12.8 cm dbh. Zone 5 is represented by mangrove vegetation of San Pedro with *Avicennia marina* as the biggest tree (37.4 cm dbh) and *R. apiculata* (23.05 m^2/ha) and *S. alba* (21.94 m^2/ha) having the relatively higher basal areas.

Physiographical classification based on location simply grouped these zones into two forest types, fringe and riverine. Riverine mangrove persists along the Iwahig and Sta Lucia river- estuaries, including the STL4, IWH2, IWH3, and

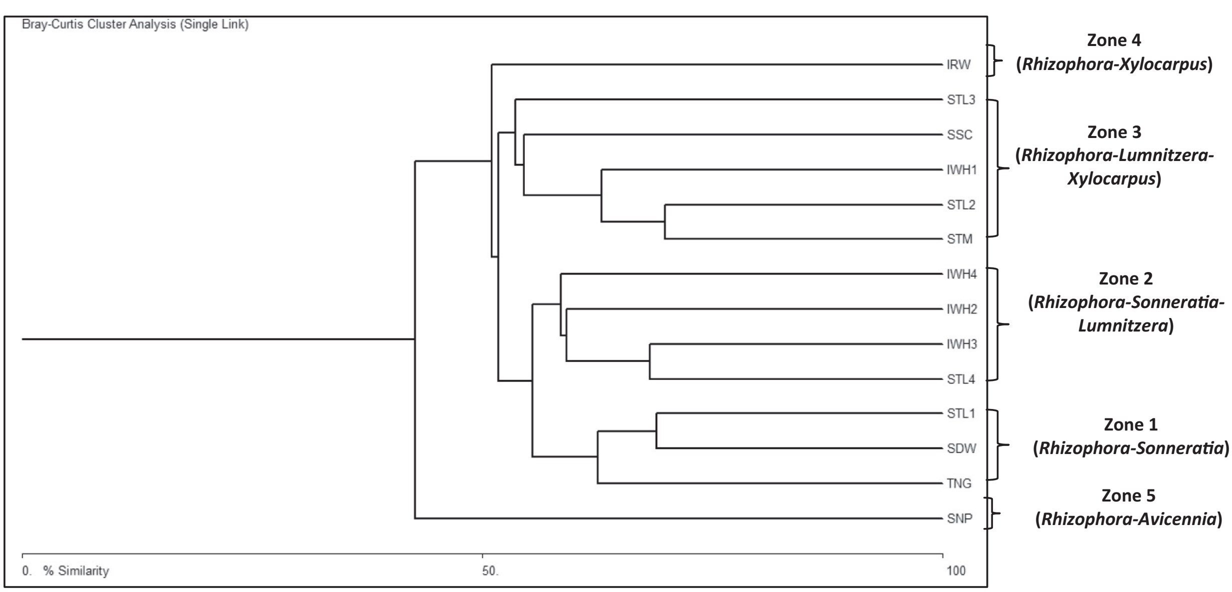


Figure 2 Cluster analysis showing the five distinct mangrove zones along Puerto Princesa Bay, Palawan and the overlapping among these zones. SNP stands for barangay San Pedro; TNG, Tiniguiban; STM, Sta Monica; SDW, Sandiwa; SSC, Sicsican, IRW, Irawan; STL1, Sta. Lucia Station 1; STL2, Sta Lucia Station 2; STL3, Sta Lucia Station 3; STL4, Sta Lucia Station 4; IWH 1, Iwahig Station 1; IWH2, Iwahig Station 2; IWH3, Iwahig Station 3; IWH 4, Iwahig Station 4.

IWH4 while fringing forest is formed toward the river mouth of Iwahig and Sta. Lucia such as the STL2 and STL3 and along the open coasts of Tiniguiban and Iwahig (Fig 3).

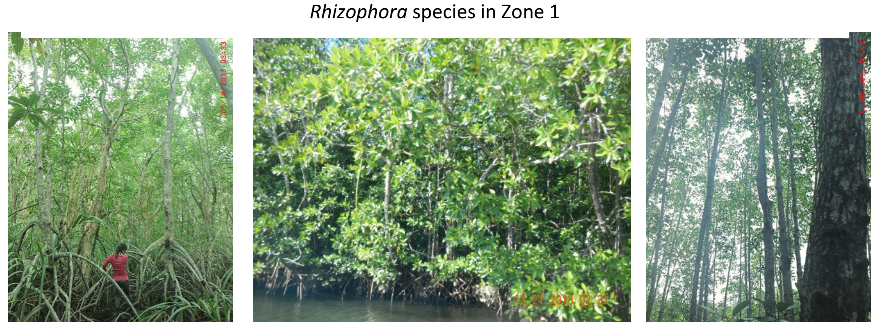
Relative dominance further examined the differences among mangrove forests based on species importance in the overall community structure. These were derived from percent relative frequency, relative density, and relative basal area of mangrove species in the study sites (Table 3). Correspondingly, the existing five mangrove zones in Puerto Princesa Bay can be named according to their respective dominant species, *Rhizophora-Sonneratia*; *Rhizophora-Sonneratia-Lumnitzera*; Rhizophora-*Lumnitzera-Xylocarpus;* *Rhizophora-Xylocarpus*; and *Rhizophora-Avicennia* zones. Evident from the cluster diagram was the overlap between (zone 1 and 2) and among (zones 1–2 and 3; zones 1–2–3 and 4; zones 1–2–3–4 and 5) zones, implying some commonality that is a normal trend in the natural environment.

Structural features e.g. the tree diameter at breast height (dbh), basal area, density and species richness differed among mangrove zones along the bay. Trees of larger dbh and higher species richness were found in zone 1 while those that comprised the highest basal area and density from zone 2 and zone 4, respectively (Table 4). Zone 1 is a fringing mangrove situated at Tiniguiban Cove while zone 2 is a riverine situated along the elevated landward portion of Sta Lucia and Iwahig River-estuaries. Zone 4 or the Irawan station includes an area planted with *Rhizophora* species thus tree density there was high, 8100 trees but of lower total basal area, only 106.22 m^2/ha as opposed to at most 438.0 m^2/ha from only 5800 tress at zone 2. Trees of intermediate dbh and basal were recorded from zone 3, which comprised the open coast fringing mangrove. Zone 5 is also situated in Tiniguiban Cove but unlike zone 1, it had a sparse mangrove distribution, only 800 trees/ha with comparable tree basal area due to the pres-

Sonneratia caseolaris and Nypa fruitican (from left to right) in Zone 2

Rhizophora spp, *Lumnitzera littorea*, and *Xylocarpus granatum* (from left to right) in Zone 2

Rhizophora species in Zone 1



Rhizophora species in Zone 3

Figure 3 Some features of riverine (A) and fringe (B) mangrove forests along Puerto Princesa Bay, Palawan Island, Philippines.

Table 3 Relative dominance (%) of common species from mangrove zones of Puerto Princesa Bay, Palawan Island, Philippines.

Mangrove scientific name	Relative dominance (%) in five sampling zones					Total	Rank
	1	2	3	4	5		
Aegiceras corniculatum	7.8					7.8	14
Aegiceras floridum	16.1					16.1	12
Bruguiera sexangula		12.3			10.2	22.5	10
Ceriops decandra	10.0	18.1	10.8	5.6		44.5	5
Ceriops tagal	10.8				9.9	20.7	11
Lumnitzera littorea	7.6	32.8	26.9			67.3	2
Rhizophora apiculata	26.0	21.2	34.7	12.1	42.3	136.2	1
Rhizophora mucronata		10.4	13.3	17.0	5.2	45.9	4
Rhizophora stylosa			10.6	29.2		39.8	6
Scyphiphora hydrophyllacea		11.3	11.7			23.01	9
Sonneratia alba	21.9				6.3	28.2	8
Sonneratia caseolaris		64.1				64.1	3
Xylocarpus granatum			14.6			14.6	13
Xylocarpus moluccensis			13.6	21.2	4.1	38.9	7
Total	100	170	136	85	78	569	
Rank	3	1	2	5	4		

Table 4 Some structural features of mangroves along Puerto Princesa Bay, Palawan Island, Philippines. DBH stands for Diameter at Breast Height; standard deviation in bracket.

Mangrove zone	No. of plots	Mean DBH (cm)	Basal Area (m^{-2} ha^{-1})	Density (tree ha^{-1})	Number of species
1	11	10.2 (3.4)–104.5 (147.3)	24.64–165.01	666–5200	4–15
2	13	5.9 (7.1)–28.1 (14.1)	40.84–438.0	2166–5800	2–8
3	13	6.8 (2.8)–26.2 (31.9)	36.71–176.89	3166–5450	6–10
4	4	9.6 (6.4)	106.22	8100	8
5	4	90.8 (80.2)	94.48	800	14

ence of a number of relatively huge *Avicennia* stands in this zone.

Human-resource interaction

In terms of anthropogenic disturbances on mangrove forest along Puerto Princesa Bay, zone 1 was found free from deforestation though TNG and SDW were more prone to garbage dumping due to their proximity to human settlement. Plastic bags, used fishing nets, and rubber strips were usually found entangled on prop roots and branches of mangroves in this zone. On the other hand, the Iwahig and Sta Lucia river-estuary portions were quite protected except for a few isolated areas where unregulated human access for occasional cutting and/or harvesting of *Ceriops* and *Nypa* was observed. The presence of Iwahig Community Tourism and Environment Association (ICTEA) and Iwahig Prison and Penal Farm somehow imposed protection measures on mangrove resource in the vicinity. In contrast though, the lower portion of the Iwahig riverbank was heavily populated. Presidential Proclamation No. 718 in 2004 allowed for segregation of parcel of land from Iwahig Prison and Penal Farm as civil reservation for resettlement and agricultural purposes, which later paved the way for establishment of "Bucana-Matahimik" resettlement project of the City of Puerto Princesa. Table 5 presents the count frequency of each human-related disturbance to mangrove forest as revealed by the key informants.

Table 5 Human-related disturbances to mangrove forest along the bay as revealed by the key informants.

Human-related disturbance	Frequency
Increased human population	23
Mangrove deforestation	17
Garbage dumping/improper waste disposal	6
Shellfish harvesting	2
Quarrying/fishpond construction	1
Soil erosion due to boat operation	1
Firefly watching/recreational activity	1

Discussion

Species diversity

The mangrove forest of Puerto Princesa Bay is more diverse, with 28 mangrove species, compared to other surveyed mangrove sites in Palawan (PCSDS, 2006, 2004, 1999). The figure constitutes nearly 75% of the Philippine mangrove species. High diversity and cover of mangroves in the area would explain the occurrence of a wide array of mangrove-associated vertebrates (Dangan-Galon et al., unpublished) and invertebrates of mariculture importance (Dolorosa and Dangan-Galon, 2014).

True mangroves along the bay constitute 27 species following the classification of Tomlinson (1986). In a more recent classification made by Primavera et al. (2004), a slight discrepancy can be noticed. The authors considered *Acanthus* as true mangrove and *Acrostichum* as associate, which is opposite to that of Tomlinson (1986). Discrepancy on species categorization may depend greatly on the manner by which authors characterized the plant. Primavera and Subada used spatial distribution as basis to delineate *Acrostichum* as mangrove associate, occupying the landward portion of mangrove forest, which may be obvious in Panay Island, where the study was conducted. Tomlinson (1986) on the other hand categorized mangroves as major, minor element (regarded in this study as the true mangrove species), and associates on cosmopolitan basis. Accordingly, spatial distribution of *Acrostichum* is not limited to elevated sites but may be found interspaced with mangrove tress in disturbed areas, which is true to some surveyed sites along the Iwahig Riverbank.

An earlier report of 18 true mangrove species from the bay did not include *Osbornia octodonta* and *Scyphiphora hydrophallacea* as true mangroves rather mangrove associates (PCSDS, 2006) and therefore did not conform to the classification scheme of Tomlinson (1986). Regardless of such inconsistency, the present study remains to indicate the highest number of mangrove species recorded from the bay with five additional species, the *A. marina*, *Avicennia officinales*, *Avicennia rumphiana*, *Aegiceras corniculatum*, and *Heritiera littoralis*. These species were frequently found in San Pedro, Tiniguiban, and Iwahig River-estuary. These areas were not included in 2005 mangrove survey of PCSDS.

Vegetation types

Mangrove forest is structurally simple with only two vegetation types. A complex forest includes other vegetation e.g. the basin, over-wash, scrub, and hammock (Clough, 2013; Hogarth, 2007; Feller and Sitnik, 1996). The presence or absence of one vegetation type may be related not only to natural and anthropogenic disturbances but also to site's geomorphology and hydrology (Urrego et al., 2014). As observed, tidal inundation, light intensity, and substrate composition have major influence on structural composition of mangroves along the bay although these variables were not measured empirically.

Human-resource interaction

Apparently, mangroves in some parts of the bay especially those in Iwahig and Sta. Lucia had remained intact over the years. The presence of fireflies, which serves as tourist attraction in Iwahig River-estuary, is an indicator of a pristine mangrove ecosystem. The observed disturbances may be recent and the adverse effects on species composition and structure are still insignificant. Forest conversion into fishpond, which is the major culprit to mangrove species loss or decline in the Philippines (Walters, 2004; Primavera and Esteban, 2008) is not rampant in the said stations. The presence of Iwahig Prison and Penal Farms in Iwahig-Sta Lucia probably imposed some sort of regulation on forest destruction in the vicinity.

At present though, sustainability of mangrove resource along the bay could not be ascertain. As mentioned, a portion of Iwahig riverbank had been converted into human resettlement. With increasing number of households residing in the bank, soil erosion, habitat destruction, and resource exploitation shall be inevitable in the near future.

Conclusion

Conservation effort, additional livelihood opportunities for the community, and information education campaign (IEC) are needed to protect the bay's mangrove forest from expanding human population in the area. Protecting the mangrove forest and utilizing it sustainably could increase the coastal inhabitant's resilience to foreseen impacts of climate change.

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